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Full Length Research Paper

Comparison of waterbird species composition and habitat characteristics of two different wetlands of Malaysia

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Waterbird species composition and habitat characteristics at two ecologically different wetlands (Paya Indah and Putrajaya) were compared in order to determine the habitat suitability of each particular habitat for waterbird species. A total of 30 waterbird species representing 10 families were recorded through direct observation in both wetland habitats (26 waterbird species in Paya Indah and 22 species in Putrajaya wetland habitats). Out of 30 waterbird species, 17 species were commonly recorded from both habitats, 4 species were absent in Paya Indah and 8 species in Putrajaya. Ardeidae was the dominant family based on the number species (11 waterbird species) while Charadriidae, Ciconiidae, Jacanidae, Pelicanidae and Podicipedidae were the rarest families (only one species was recorded) in both wetland habitats. This indicated that both wetland habitats may vary in waterbird species composition habitat characteristics, that is, a total of 34 aquatic plant species (21 species in Paya Indah and 18 species in Putrajaya wetland) belonging to 14 families were sampled during study period. Five plant species, namely, Water Chestnut– *Eleocharis dulcis,* Twig Rush– *Lepironia articulate,* Blue Lotus– *Nymphaea nouchali,* Common Reed– *Phragmites karaka* and Cattail– *Typha angustifolia* were commonly recorded from both habitats. However, 13 aquatic plant species were absent in Paya Indah and 16 species in Putrajaya wetland. The findings of this study, revealed that Paya Indah wetland is rich in waterbird species composition and habitat characteristics as compared to Putrajaya wetland habitat. This might be due to the richness and diversity of aquatic vegetation composition, occurrence of suitable foraging and breeding sites that had attracted the highest number of waterbird species to utilize the Paya Indah wetland habitat.

Key words: Waterbirds, aquatic vegetation, Paya Indah, wetland.

INTRODUCTION

Wetlands are shallow waterlogged areas where soil is saturated with water and covered by a variety of aquatic vegetation such as submerged and emergent vegetation. Wetlands may vary in habitat characteristics and productivity due to difference in topography, soil, hydrology, water quality, vegetation species composition

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and the surrounding landscape. Wetland always offers diverse habitats for a variety of fauna species, especially waterbirds, fishes, reptiles, mammals and aquatic invertebrates. They had attracted a wide array of waterbird species, that is, especially endangered and threatened waterbirds namely: *Ciconia stromi*, *Tringa guttifer*, *Egretta eulophotes*, *Mycteria cinerea*, *Lepotilos javanicus, Euryorhynchus pygmeus, Pluvialis apricaria*, *Gallinago gallinago, Calidris alpine, Limosa limosa, Thinornis rubricollis* and *Vanellus vanellus,* (Ishikawa et al., 2003; Stroud et al., 2004) as compared to other aquatic habitats and they need special attention for conservation.

Waterbirds are ubiquitous components of wetland ecosystems, that is, top predators and may have effect on the distribution and richness of fishes and other fauna (Steinmetz et al., 2003; Garcia and Yorio, 2007). Waterbirds utilized different wetland habitats for nesting, breeding, foraging, stopover and wintering grounds during migration (Romano et al., 2005; Guadagnin et al., 2005; Junk et al., 2006; O'Neal et al., 2008; Saygill et al., 2011). The waterbird species richness and abundance are influenced by environmental factors such as water level fluctuation, water depth, habitat richness and ecological interactions, that is, predators, richness of food and competition (Guadagnin et al., 2005; Cintra et al., 2007; Cintra, 2012). They are consumers and bio-indicators, that is, their presence or absence may indicate the current status of a particular dwelling wetlands habitat.

It has been stated that >50.0% world's wetland areas had been lost (Fraser and Keddy, 2005; Battisti et al., 2008) due to human induced activities such as discharge of urban sewage, pesticide runoff off from surrounding agricultural fields (Melink and Riojas-Lopez, 2009), draining for conversation into agricultural fields and development of housing societies (Gautam and Kafle, 2007; Kafle et al., 2008). The habitat loss and degradation had adversely affected the population of many waterbird species such as rails, storks, grebes, jacanas and waders, etc, across the world (Ma et al., 2010). Fruther more, some are critically endangered, threatened and extinct due to habitat loss and degradation (O'Connell, 2000; Deluca et al., 2008; Delany et al., 2010; Suazo et al., 2012; Lafferty et al., 2013).

A detailed research on waterbird species composition and habitat characteristics across Malaysia is still lacking. Few studies have been conducted in various wetland habitats on waterbird species and habitat characteristics. For example, effects of water quality in oil palm production landscapes on tropical waterbirds in Peninsular Malaysia (Sulai et al., 2015), the relationships between morphological characteristics and foraging behavior in four selected species of shorebirds and water birds utilizing tropical mudflats (Norazlimi and Ramli, 2015), effects of habitat characteristics on waterbird distribution and richness in wetland ecosystem of Malaysia (Rajpar and Zakaria, 2014), assessing the habitat suitability of two different artificial wetland habitats using avian community structures (Rajpar and Zakaria, 2014) and assessing an artificial wetland in Putrajaya, Malaysia, as an alternate habitat for waterbirds (Rajpar and Zakaria, 2013). There is an urgent need to determine and compare the waterbird species inhabiting different wetland habitats in order to understand the habitat suitability and productivity for waterbird species for future conservation and management plans. The main objectives of this study were to determine and compare the waterbird species and habitat characteristics of Paya Indah and Putrajaya wetland for future conservation and better management activities.

METHODOLOGY

Study site 1

Paya Indah Wetland (a wildlife sanctuary) encompasses of 3050 ha, out of which 450 ha are under the administration of the Department of Wildlife and National Parks, Peninsular Malaysia. The study area (Figure 1) is located within the quadrant of 101°10′ to 101°50′ longitude and 2°50′ and 3°00′ latitude.

Study site 2

Putrajaya wetland is situated around 26 km away from Kuala Lumpur within the quadrant of 2° 57' 43" latitude and 101° 41' 47" longitude (Figure 1). This wetland straddles the water from the catchment areas of Chua and Bisa Rivers and covers an area of 200 ha (77.70ha planted area, 76.80 ha open water bodies, 9.60 ha islands, 23.70 ha inundation area and 9.40 ha tracks).

Waterbird surveys

Monthly waterbird surveys were carried out from January to December, 2011 employing direct visual observation. The presence of waterbirds was determined by using the point count method employing direct observation and employing 10 × 50 binocular. A total of 100 point stations (50 points in each wetland) were established to detect the different waterbird species inhabiting both wetlands. The location of each point count station was established at intervals of 300 m apart to avoid the double counting of the same waterbird species at more than one station (Figures 2 and 3). The survey of waterbird species was carried out early in the morning, that is, between 0730 and 1000 h, and mostly waterbird species were active during the morning hours and easy to observe. The methodology described by Aynalem and Bekele (2008), Zakaria et al. (2009) and Rajpar and Zakaria (2014) was followed.

Vegetation survey

The aquatic vegetation composition of Paya Indah and Putrajya wetland habitats was determined by employing 10 x 10 m quadrant method. This method had been widely used to study the vegetation of heterogeneous habitats (Fernandez-Alaez et al., 2002). Sixty quadrant plots) 30 sample plots in each habitats) were sampled along the edges and in shallow water to examine the aquatic vegetation composition of both study sites. In each sample plot,

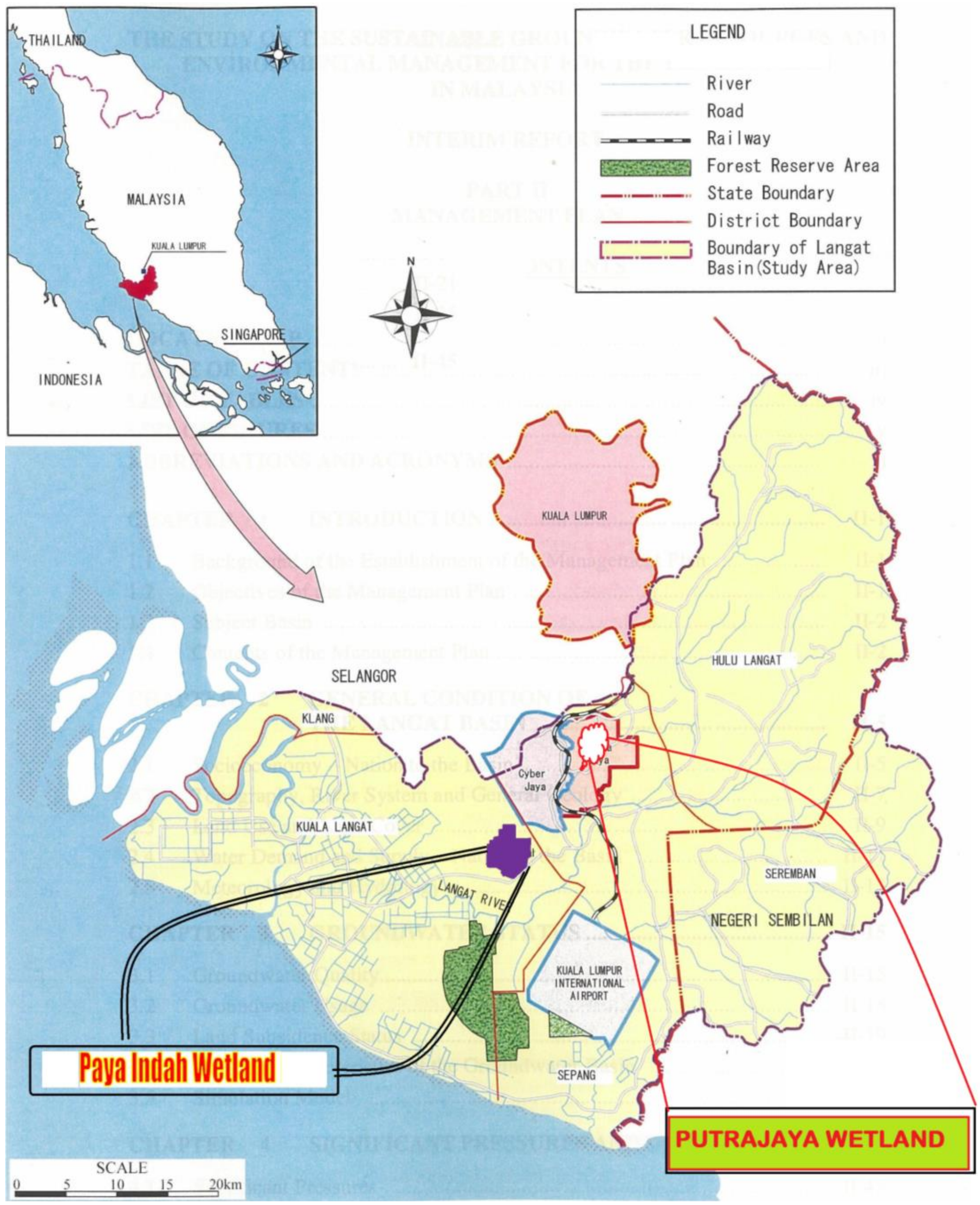

Figure 1. Location map of the study areas.

vegetation cover % (the proportion of the water surface covered with aquatic vegetation), vegetation type (emerged and submerged vegetation, sedges, reeds, ferns and grasses) were recorded. The methodology was followed as described by Isacch et al. (2005).

RESULTS

Waterbird species composition of Paya Indah and Putrajaya wetland

A total of 30 waterbird species representing 10 families were recorded through direct visual observation in both wetland areas, that is, Paya Indah and Putrajaya wetland habitats. Out of 30 waterbird species, 26 were recorded in Paya Indah wetland and 22 waterbird species from Putrajaya wetland habitats. Out of 30 waterbird species, 17 species were commonly recorded in both wetland habitats. However, 4 waterbird species were absent in Paya Indah wetland and 8 were absent in Putrajaya wetland, respectively. Ardeidae (11 waterbird species) and Rallidae (6 species) were the most dominant families of waterbirds in both wetland habitats. In contrast, five

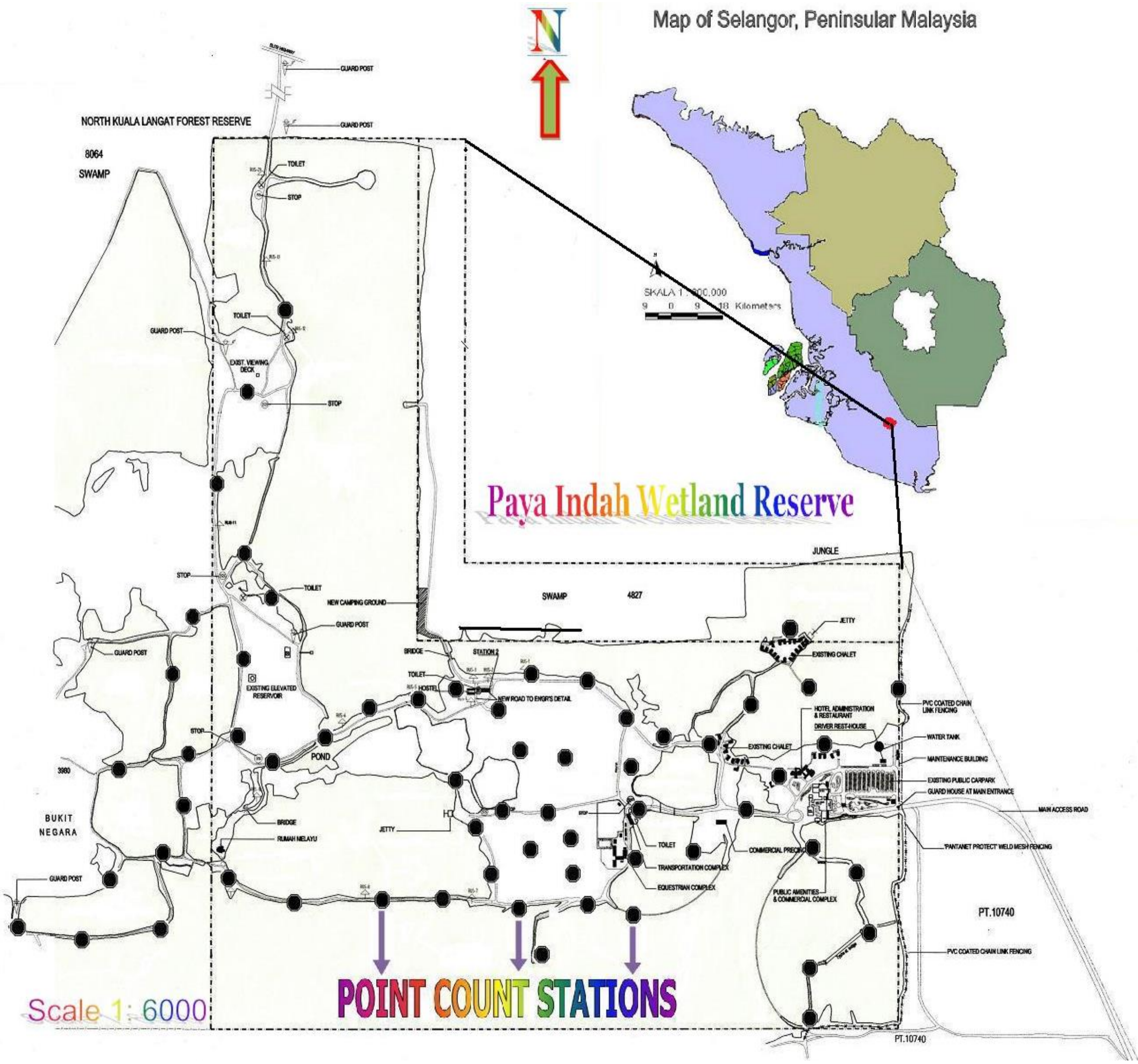

Figure 2. Location map of point count stations at Paya Indah wetland.

families, that is, Charadriidae, Ciconiidae, Jacanidae, Pelicanidae and Podicipedidae were the rarest families (only one species was recorded from each family) of Paya Indah and Putrajaya wetland habitats. This indicated that both wetland habitats may vary in waterbird species composition and habitat characteristics (Table 1).

Wetland vegetation composition of Paya Indah and Putrajaya habitat

The results indicated that vegetation of Paya Indah and Putrajaya wetland habitat vary in species composition. A total of 34 aquatic plant species (21 species in Paya Indah and 18 species from Putrajaya wetland) representing 14 families were sampled from both wetland habitats. Five plant species, namely Water Chestnut– *Eleocharis dulcis,* Twig Rush– *Lepironia articulate,* Blue Lotus– *Nymphaea nouchali,* Common Reed– *Phragmites karaka* and Cattail– *Typha angustifolia* were commonly detected from both habitats. However, 13 aquatic plant species were absent in Paya Indah and 16 species in the Putrajaya wetland habitat. The results revealed that Cyperaceae (13 plant species) was the most dominant family while 10 families were rarest in both wetland habitats (Table 2).

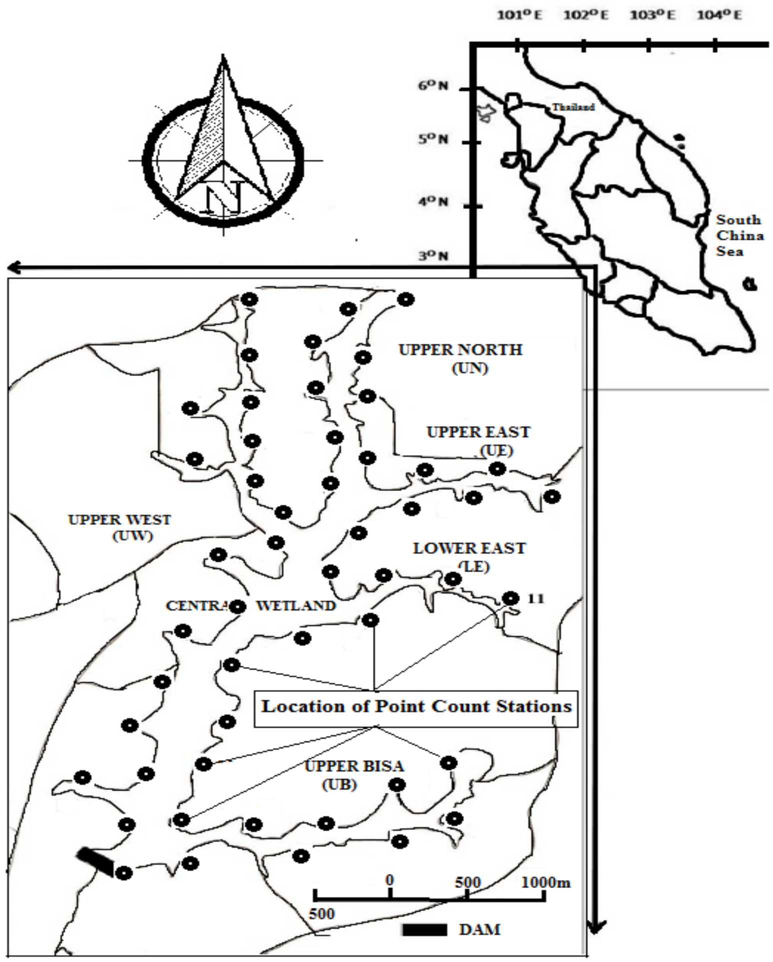

Figure 3. Location map of point count stations at Putrajaya wetland.

Table 1. List of waterbird species recorded in Paya Indah and Putrajaya wetlands.

Family Name	Species Common Name	Species Scientific Name	PIW	PW
Alcidinidae	Common Kingfisher	*Alcedo atthis*	X	X
	White-throated Kingfisher	*Halcyon smyrensis*	X	X
	Black-capped Kingfisher	*Alcedo atthis*	X	–
	Stork-billed Kingfisher	*Pelargopsis capensis*	X	–
Anatidae	Lesser Whistling Duck	*Dendrocygna javanica*	X	–
	Cotton Pygmy Goose	*Nettapus coromandelianus*	X	–
Ardeidae	Black-crowned Nightheron	*Nycticorax nycticorax*	X	X
	Cattle Egret	*Bubulcus ibis*	–	X
	Great Egret	*Chasmerodius albus*	X	X
	Grey Heron	*Ardea cinerea*	X	X
	Javan Pond Heron	*Ardeola speciosa*	–	X
	Little Egret	*Egretta garzetta*	X	X
	Little Heron	*Butorides striatus*	X	X
	Purple Heron	*Ardea purpurea*	X	X
	Yellow Bittern	*Ixobrychus sinensis*	X	X

Table 1. Contd.

	Cinnamon Bittern	*Ixobrychus cinnamoneus*	X	X
	Schrenck's Bittern	*Ixobrychus eurhythmus*	X	–
Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	X	X
Ciconiidae	Painted Stork	*Mycteria leucocephala*	–	X
Pelicanidae	Great White Pelican	*Pelecanus onocrotalus*	–	X
Jacanidae	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	X	–
Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	X	–
Rallidae	Ballion's Crake	*Porzana pusilla*	X	–
	White-browed Crake	*Porzana cinerea*	X	–
	Common Moorhen	*Gallinula chloropus*	X	X
	Purple Swamphen	*Porphyrio porphyrio*	X	X
	White-breasted Waterhen	*Amaurornis phoenicurus*	X	X
	Water Cock	*Gallicrex cinerea*	X	X
Scolopacidae	Common Sandpiper	*Tringa hypoleucos*	X	X
	Pintail Snipe	*Gallinago stenura*	X	X

Table 2. List of wetland vegetation recorded at Paya Indah and Putrajaya wetlands.

Family Name	Scientific Name	Common English Name	Paya Indah	Putrajaya
Alismataceae	*Sagittaria latifolia*	Duck-Potato	X	–
Amaryllidaceae	*Crinum defixum*	Wild Garlic	–	X
Blechnaceae	*Stenochlaena palustris*	Climbing Fern	X	–
Cyperaceae	*Carex* spp.	Swamp Grass	X	–
	Cyperus halpan	Dwarf Papyrus Sedge	–	X
	Eleocharis dulcis	Water Chest-Nut	X	X
	Eleocharis variegata	Chinese Water Chestnut	–	X
	Fimbristylis globulosa	Globe Fimbry	–	X
	Fuirena umbellata	Yefen	–	X
	Lepironia articulata	Twig Rush	X	X
	Rhynchospora corymbosa	Golden Beak-Sedge	–	X
	Scirpus grossus	Giant Bulrush	–	X
	Scirpus mucronatus	Bog Bulrush	–	X
	Scirpus olneyi	Three Square Bulrush	X	–
	Scleria purpurascens	Marsh Sedge/Nut Rush	X	–
	Scleria sumatrensis	Nut Rush	–	X
Graminae	*Distichlis spicata*	Spike Grass	X	–
	Imperata cylindrica	Cogon Grass	X	–
Lycopodiatae	*Lycopodium cernuum*	Creeping Club Moss	X	–
Mackinlayaceae	*Centella asiatica*	Gotu Kola	–	X
Nymphaeaceae	*Nelumbo nucifera*	Indian/Sacred Lotus	X	–
	Nelumbo pubescens	Water Lily	X	–
	Nymphaea nouchali	Blue Lotus	X	X

Table 2. Contd.

	Nymphaea rubra	Rubra Water Lily	X	–
Onagraceae	*Ludwigia palustris*	Water Purslane	–	X
Philydraceae	*Philydrum lanuginosum*	Wooly Water Lily	X	–
	Phragmites karaka	Common Reed	X	X
Poaceae	*Echinochloa crus-galli*	Barnyard Grass	–	X
	Panicum maximum	Buffalo Grass	X	–
	Panicum repens	Torpedo Grass	X	–
	Spartina alterniflora	Rush	X	–
Polygonaceae	*Polygonum barbatum*	Knot Grass	–	X
Salviniaceae	*Salvinia molesta*	Giant or Kariba Weed	X	–
Typhaceae	*Typha angustifolia*	Cattail	X	X

DISCUSSION

The recording of 30 waterbird species in both habitats indicated that they are suitable habitat of the wide array of waterbird species. The recording of 26 waterbird species at Paya Indah and 22 species in Putrajaya wetland showed that Paya Indah had attracted more waterbird species as compared to Putrajaya wetland. The difference in waterbird species composition could be due to variation in vegetation structure, habitat heterogeneity, food resources and foraging behaviour of waterbird species. For example, egrets and herons were more abundant in the Putrajaya wetland as compared to Paya Indah wetland. This might be due to availability of islands dominated by trees and shallow depth of water, which offer ideal foraging and nesting sites for egrets and herons (Elbin and Tsipoura, 2010). On the other hand, a higher number of waterbird individuals such as swamphen, moorhen, watercock, sandpipers, lapwings and kingfishers were observed at Paya Indah wetland habitat than Putrajaya wetland. The occurrence of higher number of these waterbird species could be due to availability of dense aquatic vegetation which forms thick mats in the center of wetland and offer suitable foraging and breeding sites for them. The other reason could be that swamphen moorhen, watercock and sandpipers are a shy species with secretive behaviour and avoid using the open areas and urban habitats (George and Zack, 2001; Voshell and Wright, 2002; Ross et al., 2011).

Fruther more, the sampling of 21 aquatic plant species at Paya Indah and 18 aquatic plant species at Putrajaya habitats indicated that both habitat may vary in vegetation structure and composition. For example, Paya Indah wetland is dominated by *Nelumbo nucifera, Nelumbo pubescens, Nymphaea nouchali, Nymphaea rubra, Scirpus olneyi, Scleria purpurascens, Distichlis spicata, Lycopodium cernuum, Philydrum lanuginosum, Panicum* sp., *Spartina alterniflora* and *Salvinia molesta.* On the contrarily, Putrajaya wetland is dominated by *Cyperus halpan, Eleocharis variegate, Fimbristylis globulosa, Fuirena umbellate, Rhynchospora corymbosa, Scirpus* sp., *Scleria sumatrensis, Centella asiatica, Nymphaea nouchali, Echinochloa crus-galli* and *Polygonum barbatum.* The difference in wetland vegetation and structure could be due to variation in water level and quality, surrounded landscape, and the inflow of water from the catchment area. Putrajaya wetland is surrounded by the catchment of river Chua and Baisa and is shallow in water depth (Rajpar and Zakaria, 2013) while Paya Indah wetland is surrounded by housing societies and agriculture fields, oil-palm plantation and peat swamp forest. The variation in aquatic vegetation structure and composition might have created a variety of microhabitats which had attracted a wide array of waterbird species to utilize the different areas of wetlands in order to satisfy their needs to perform various activities. It has been illustrated that habitat structure of wetland may vary depending upon water supply and surrounding landscapes (Winter et al., 2005). Waterbirds often select available wetland habitats which provide plenty of food resources, protection from predators and harsh weather and also offer suitable breeding sites for them (Marshall and Cooper, 2004; Cunningham et al., 2008; Rajpar and Zakaria, 2011).

Conclusion

Overall, the findings of this study revealed that Paya Indah wetland is rich in waterbird species composition and habitat characteristics as compared to Putrajaya wetland habitat. This might be due to the richness and diversity of aquatic vegetation, occurrence of suitable foraging and breeding sites for different waterbird species, especially ducks, goose, swamphen, moorhen, crakes, jacanas and sandpipers. These waterbird species are secretive in behaviour, that is, shy species and often prefer large waterbodies dominated by thick aquatic vegetation. The other reason could be that Paya Indah wetland is deep, wide and interconnected with a chain of wetlands, while Putrajaya wetland is shallow and running in between the buildings.

Conflict of interests

The authors did not declare any conflict of interest.

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Full Length Research Paper

Regional Glacier recession: An indicator of global warming, a study of Kolahoi Glacier (Liddar Valley), Western Himalayas

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Since the beginning of twentieth century, mountain glaciers have generally experienced worldwide retreat and thinning in response to ~0.74°C increase in global mean surface temperature. Consequently, additional fresh water is released from glacier storage that modifies current stream flow regimes. Water resources play a key role in the sustainable development of human activities and for preserving the ecological environment in the Kashmir valley. Glaciers have a substantial influence on the local water cycle by temporarily storing water as snow and ice on many different time-scales. Scientific communities and sectors of water resources management have recently recognized the strong influence of glaciers on catchment runoff quantity and distribution. In this backdrop, an attempt has been made to examine how climatic change influences glacier behaviour and the water quantity from its discharge. A study of the Kolahoi Glacier, Liddar Headwater, Kashmir Himalayas, is presented here. The study was carried out using Remote Sensing and Geographic Information Systems (GIS) techniques. The Kolahoi Glacier shows a faster retreat than other Kashmir Himalayan glaciers. The area of the glacier receded from 11.22 km² in 1992 to 9.80 km² in 2010, registering a change of 1.42 km^2 in 18 years at a rate of 0.078 km^2 per year. As the glacier is receding very fast during the recent time its discharge also shows an increasing trend. The result of this retreat will prove disastrous for the valley in a number of ways like drinking water, agriculture, horticulture, ground water, hydro power capacity of the state, etc. Therefore, efforts need to made to save this precious source of water for the present as well as for future generations.

Key words: Climatic change, remote sensing, Kolahoi Glacier, Liddar, Kashmir Himalayas.

INTRODUCTION

Glaciers are dynamic and fragile ice bodies on the landscape which have changed in the past and will continue to change in response to the pulsations in the climatic scenario. Change in climate is clearly reflected in mass and temperature changes of glaciers. Hence, the perennial land ice bodies are considered the key for

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climate system studies. Glacier advancement and recession are the most significant evidences of change in glacier geometry. Shifting of snout position of glacier as a response to climatic changes is the best indicator of glacier advancement and recession over a period of a few years or decades. During Pleistocene period, the glaciers occupied about 30% of the total area of earth as against 10% area at present (Flint, 1964). Glaciers are retreating in the face of accelerated global warming resulting in the long-term loss of natural fresh water storage. Since industrialization, human activities have resulted in steadily increasing concentrations of greenhouse gases in the atmosphere, leading to fears of enhanced greenhouse effect. As a result of greenhouse gas effect, the world's average surface temperature has increased between 0.3 and 0.6°C over the past hundred years (Samjwal et al., 2006) as a result of which, the mountain glaciers have thinned, lost mass, and retreated. The Intergovernmental Panel on Climatic Change (IPCC) has stated that thinning of glaciers since the mid-19th century has been oblivious and pervasive in many parts of the world. The panel in its third assessment report revealed that the rate and duration of the warming in the 20th century is larger than at any other time during the last one thousand years. According to the IPCC (2001) and their assessments based on climate models, the increase in global temperature will continue to rise during the 21st century. The increase in the global mean temperature by 2100 could amount to anything from 1.4 to 5.8°C, depending on the climate model and greenhouse gases emission scenario (IPCC, 2001). On the Indian sub-continent, average temperatures are predicted to rise between 3.5 and 5.5°C by 2100 (Lal, 2002). An even higher increase is assumed for the Tibetan Plateau. These changes in climate will inevitably interact with changes in glacier. The climatic fluctuations affect both the amount of snow and ice stored in, and the quantities of meltwater runoff arising from the glaciers. A forecast was made that up to a quarter of the present global mountain glacier mass could disappear by 2050 and up to half could be lost by 2100 due to global warming (Kuhn, 1993; Oerlemans, 1994). For example, with the temperatures rise by 1°C, Alpine glaciers have shrunk by 40% in area and by more than 50% in volume since 1850 (CSE, 2002). A decrease of glacier mass of this magnitude presents a serious water resources problem for the millions of people living within the Himalayan region and in the adjoining plains. Glaciers in the Himalaya are receding faster than in any other part of the world.

The receding and thinning of Himalayan glaciers can be attributed primarily to the global warming due to increase in anthropogenic emission of greenhouse gases. The relatively high population density near these glaciers and consequent deforestation and land-use changes have also adversely affected these glaciers (IPCC, 2007).

The distribution of snow accumulation in mountain regions is one of the most important controls in mountain river hydrology. The variability of snow accumulation makes accurate information on snowmelt processes difficult to obtain. The amount of snow and ice melt contributions in Himalayas vary from year to year depending on the amount of precipitation at high altitudes and the prevalent environmental conditions during the melt season. Glacier discharge is dominated by melt water runoff. The amount of precipitation in the form of snow has an inverse effect on the amount of runoff. Fresh snow is highly reflective so that it absorbs less heat and melts slowly, while old snow and glacier ice have a low reflectivity. Thus, greater the precipitation in the form of snow, longer than the glacier is covered by a highly reflective material, and less than the runoff. A decreased amount of snowfall leads to a low-reflective surface being exposed longer, producing greater melt and increased runoff. There can be a considerable variation in discharge from year to year which are usually the result of fluctuations in glacier mass balance, with weather conditions and ablation rates in the summer being the most significant.

METHODOLOGY

Study area

The Liddar catchment occupies the south eastern part of the Kashmir valley (Figure 1) and is situated between 33° 45′ 01″ N - 34° 15′ 35″ N and 75° 06′ 00″ E– 75° 32′ 29″ E. The Liddar valley forms part of the middle Himalayas and lies between the Pir Panjal range in the south and south-east, the north Kashmir range in the north-east and Zanskar range in the southwest. The Liddar valley has been carved out by river Liddar, a right bank tributary of river Jhelum.

It has a catchment area of 1159.38 km^2, which constitute about 10% of the total catchment area of river Jhelum. The valley begins from the base of the two snow fields, the Kolahoi and Sheshnag, where from its two main upper streams; the west and the east Liddar originate and join near the famous tourist town of Pahalgam. It joins the Jhelum (upper stream of Indus river) at Gur village after travelling a course of 70 km. The area gradually rises in elevation from south (1600 m) to north (5425 m). The study area reveals a variegated topography due to the combined action of glaciers and rivers. The valley possesses distinctive climatic characteristics, because of its high altitude location and its geophysical setting, being enclosed on all sides by high mountain ranges. The valley is characterized by sub-Mediterranean type of climate with nearly 70% of its annual precipitation concentrated in winter and spring months.

Data set and method

In the present study, the dataset consists of the geometrically corrected Landsat ETM imagery (1992) with the resolution of 30 m, the geometrically corrected IRS 1C LISS III (2010) imagery with the resolution of 23.5 m, the meteorological data of the Liddar valley and the discharge data from the Kolahoi Glacier at Aru (west Liddar). The research was carried out, utilizing the techniques of Remote Sensing and GIS in the Erdas Imagine 9.0& Arc view 3.2a.

Before using the satellite imageries for analysis, each image was

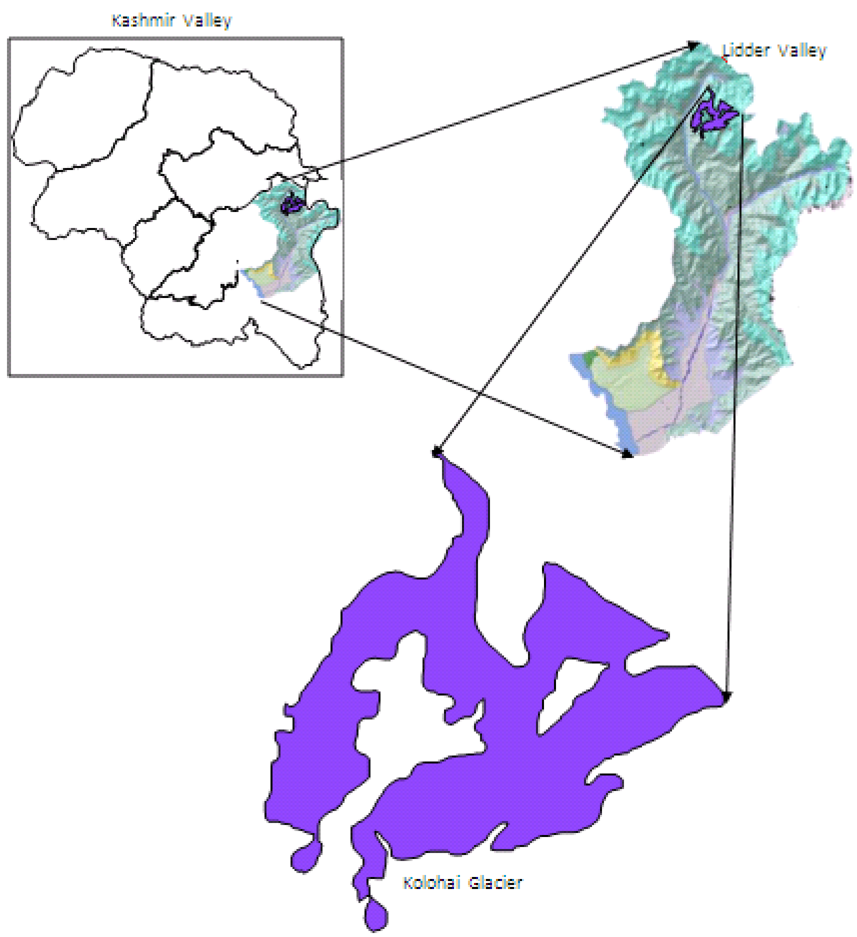


Figure 1. Location map of Study Area (Generated from SOI toposheets 1963 and ETM, 1992).

geometrically corrected and different contrast enhancements were used to enhance the interpretability of the images. The base map was prepared from ETM satellite image for the year 1992. The spatial extent of the glacier is delineated and digitized in the Arcview3.2a. The map prepared from 2010 satellite image is then superimposed on the base map prepared from 1992 satellite image in a GIS environment and the third layer was created by identifying the changed area. The findings are presented in the form of change detection map. Image selection for glacier mapping is guided by acquisition at the end of the ablation period, cloud-free conditions, and lack of snow fields adjacent to the glacier. Visual interpretation of the images has been carried out based on standard photo interpretation methods, and subsequently, digital image processing has been carried out. The images were visually interpreted, using the clues such as tone, color, texture, pattern, shadow, shape, and association, etc. To differentiate between the clouds and snow/glaciers, various color composites were analyzed. Although, all the remote sensing data were received in August and September, the seasonal snow was obvious on the images. On satellite images, glacial boundary was mapped using standard combinations of bands such as band 2 (0.52 to 0.59 mm), band 3 (0.62 to 0.68 mm) and band 4 (0.77 to 0.86 mm). Image enhancement technique was used to enhance difference between glacial and non-glacial area. Annual mean maximum and mean minimum temperature in degree Celsius (°C), and total precipitation in millimeters were calculated from year 1980 to 2010 based on the data acquired from India Meteorological Department, Srinagar. The discharge from Kolahoi Glacier (Obtained from Flood and Irrigation Department, Srinagar) was observed at the Aru-Liddar Head. The resultant data have been presented in the form of charts in order to analyze the pulsations in the climatic variables. The methodology employed for the change detection in the spatial extent of the glacier is as shown in Figure 2.

RESULTS AND DISCUSSION

Glaciers in the Kashmir valley are in a state of fast retreat. The same process of retreat is found in the Kashmir valley's largest glacier, Kolahoi (Liddar valley). Kolahoi Glacier is receding very fast due to changes that have been taking place in the climate at global level and Kashmir valley in particular. The study reveals that there has been a considerable change in the spatial extent of the glacier under study from 1992 to 2010 (Table 1 and Figure 3a, b, c). In 1992, the area of the Kolahoi Glacier was 11.22 km^2, which receded up to 9.80 km^2 in 2010, showing a net change of 1.42 km^2 in 18 years with an

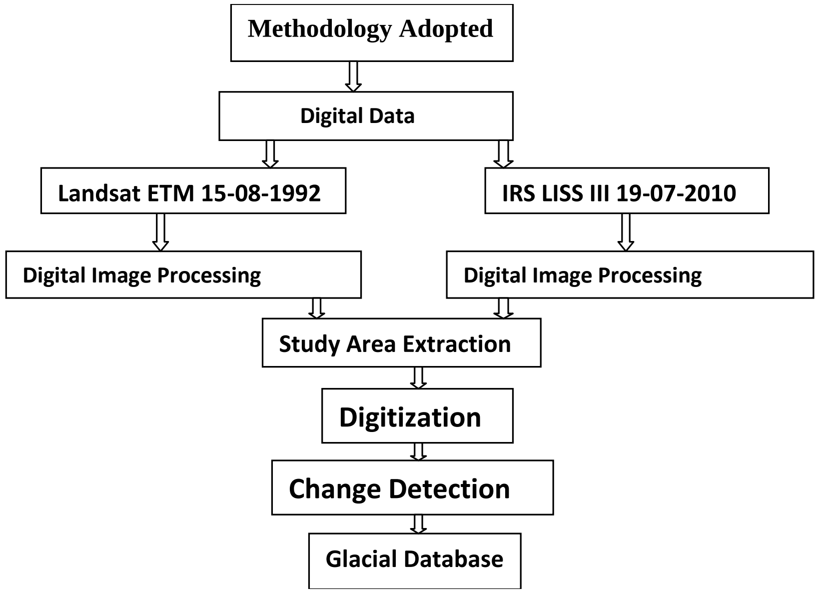


Figure 2. Flow chart of change detection.

Table 1. Change detection of Kolahoi Glacier (Computed from ETM, 1992 and IRS 1C LISS III, 2010).

Area (km^2) 1992	Area (km^2) 2010	Time interval	Change (km^2)	Rate of change (km^2/year)
11.22	9.80	18 years	1.42	0.078

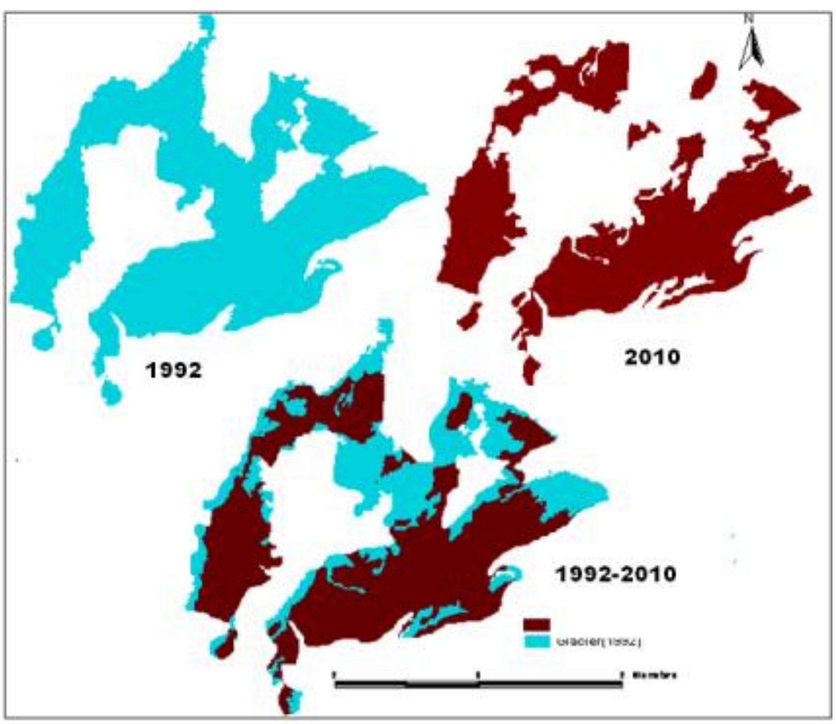
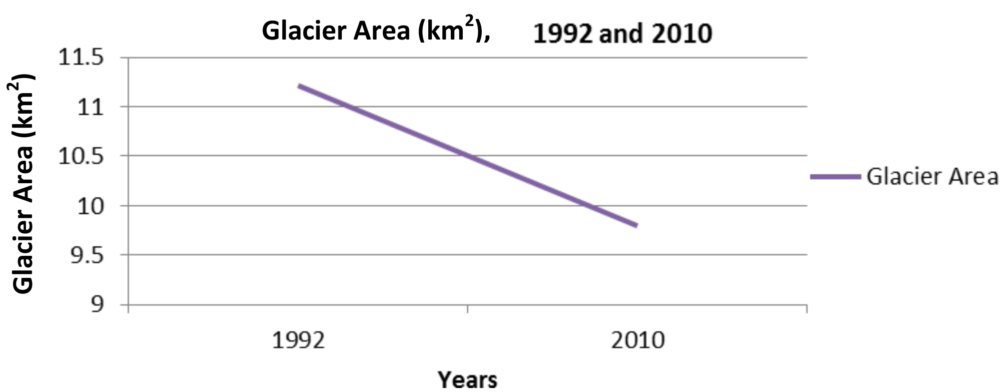


Figure 3. Glacier area- (a) 1992, (b) 2010 and change detection (c) 1992-2010 (Generated from ETM, 1992 and IRS 1C LISS III 2010).

Table 2. Mean annual values of the temperature (°C), precipitation (mm) and discharge (cusecs) in the Liddar basin (1980-2010) (India Meteorological Department, Srinagarand Flood and Irrigation Department, Srinagar).

Year	Mean annual Max. Temp. (°C)	Mean annual Min. Temp. (°C)	Total annual precipitation (mm)	Total annual discharge (Cusecs)
1980	15.84	3.26	1231	3140
1985	15.57	2.45	1147	4754
1992	17.15	3.17	1371	4100
1995	15.55	1.82	1353	3347
2000	17.53	3.19	921	3432
2005	16.3	3.49	1300	4540
2007	18.0	4.63	921	4574
2010	18.3	4.66	917	4602



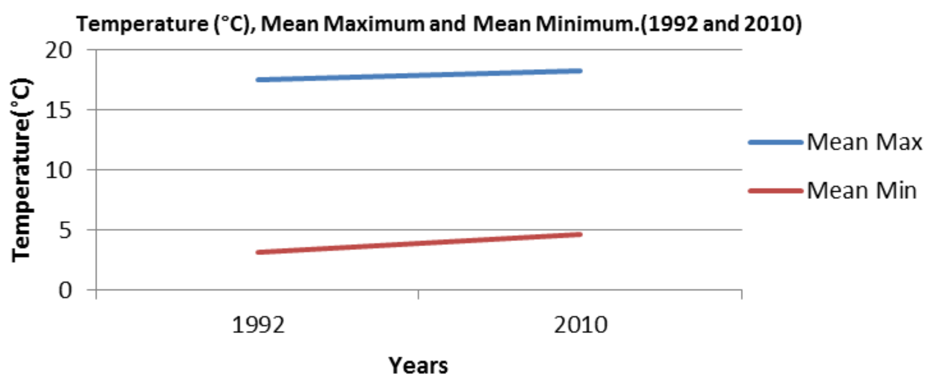


Figure 4. Comparison between total glacier area, mean maximum, and mean minimum temperatures 1992 and 2010.

average retreating rate of 0.078 km^2 per year.

Climate variability in Liddar valley

The average annual maximum temperature in the Liddar valley was 15°C in 1980 which increased to 18.0°C in 2007 and 18.3°C in 2010. The trend is consistent with the annual minimum temperature, which increases from 1.82°C in 1995 to 4.63°C in 2007 and 4.66°C in 2010. Increase in temperature conditions are corresponded by a declining trend in precipitation of the study area. The precipitation decreases from 1231 mm in 1980 to 1147 mm in 1985. It further decreases from 1371 mm in 1992 to 921 mm in 2007 and 917 mm in 2010 (Table 2). The increase in temperature (both annual maximum and minimum) and decrease in precipitation in the Kolahoi Glacier valley may have resulted in enhanced glacier ice melt. The total annual discharge from the Kolahoi Glacier increases from 3140 cusecs in 1980 to 4100 cusecs in 1992. It further increases from 3347 cusecs in 1995 to 4574 in 2007 and 4602 cusecs in 2010 (Table 2). It is evident from Figure 4 that anomalously high rates of glacier shrinkage have resulted due to the climatic

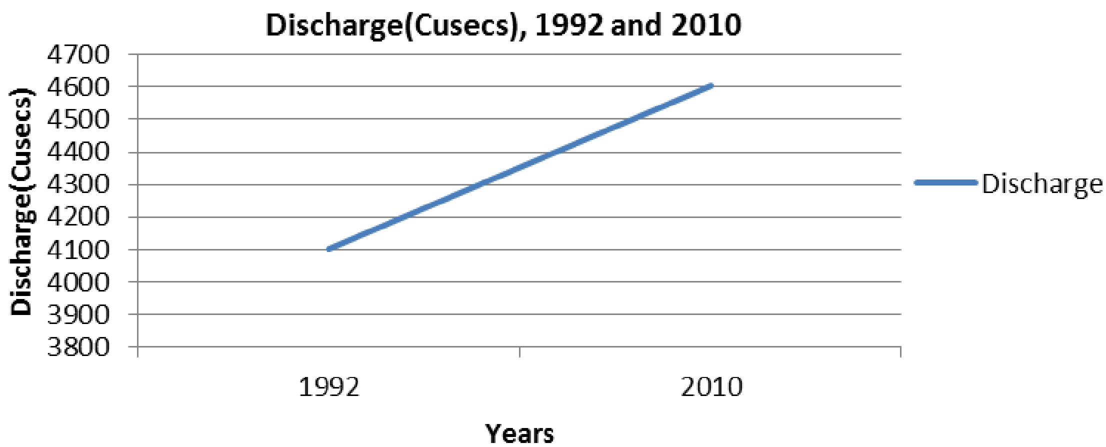


Figure 5. Discharge from Kolahoi glacier at Aru, Liddar Head (1992 and 2010).

warming. Furthermore, high rates of glacier shrinkage in the study area have resulted in high runoff which is shown in Figure 5. The temperature, precipitation, and discharge trends in the Liddar valley are shown in Figure 6. The trends indicate that the annual total discharge during the given years will increase with the increase in temperature (both annual maximum and minimum) and decrease in precipitation.

The analysis of climatic factors of the study area shows the recession is coherent with the warming trend. It can be said that, increasing trend of both minimum and maximum temperatures are responsible for areal decrease with the effect of melting. Furthermore, the precipitation values over years have also shown a declining trend. This may be because of the decline in the relative humidity in the study area. The alarming increase in mean maximum temperature in Liddar valley induces rapid melting of snow, whereas the increase in mean minimum temperature does not allow glaciers to freeze to required extent and ultimately affects its life span. The mean annual values of temperature, precipitation and discharge for the years 1980 to 2010 in the Liddar basin are shown in Table 2.

Conclusions

Glaciers are in the process of retreat in almost all the parts of the world due to global warming. The same process of retreat is found in the valley's largest glacier, Kolahoi. Its area in the year 1992 was 11.22 km^2 which receded up to 9.80 km^2 in the year 2010, a net decrease of about 1.42 km^2 in 18 years at the rate of 0.078 km^2 per year.

The hydro meteorological data of the study area shows an increase in the mean maximum and mean minimum temperatures and a decrease in the precipitation pattern. The annual mean maximum temperature increases from 15.84°C in 1980 to 18°C in 2007 and 18.3°C in 2010. The annual mean minimum temperature increases from 3.26°C in 1980 to 4.63°C in 2007 and 4.66°C in 2010. The precipitation declines from 1231 mm in 1980 to 921 mm in 2007 and 917 mm in 2010. This alarming increase in mean maximum temperature in Liddar valley induces rapid melting of snow, whereas the increase in mean minimum temperature does not allow glaciers to freeze to required extent and ultimately affects its life span. Increase in temperature conditions is facilitated by a corresponding declining trend in precipitation. Variations in the Kolahoi Glacier depend strongly on the temperature conditions. Therefore, in the case of low precipitation, rising temperature will reduce accumulation and this intensifies the ablation increase. Glaciers are important storage of fresh water in Kashmir as they accumulate mass; particularly, in the winter and provide melt water at lower elevation. The importance of glaciers is not only limited to Kashmir only: all the water from Jhelum finally falls in the Indus. Therefore, any significant change in glacier mass is certain to impact water resources on a regional level.

The discharge data from the Kolahoi Glacier at Aru shows a net increase in its discharge. This is due to the increase in the glacier melt and subsequent runoff. The total annual discharge from the Kolahoi Glacier increased from 3140 cusecs in 1980 to 4574 cusecs in 2007 and 4602 cusecs in 2010. The large increase of glacial melt water is also testified by the breaking of glacial ice at several places in Kolahoi Glacier.

Kolahoi Glacier is receding at a very fast rate due to both anthropogenic and natural causes like increase in temperature, deforestation, tourism, increased activity of Gujjars and Bakerwals, high levels of pollution caused by the emission of greenhouse gases, military vehicular movement, cement plants, etc. The result of this retreat will prove disastrous for the valley in many fields like drinking water, agriculture, horticulture, ground water,

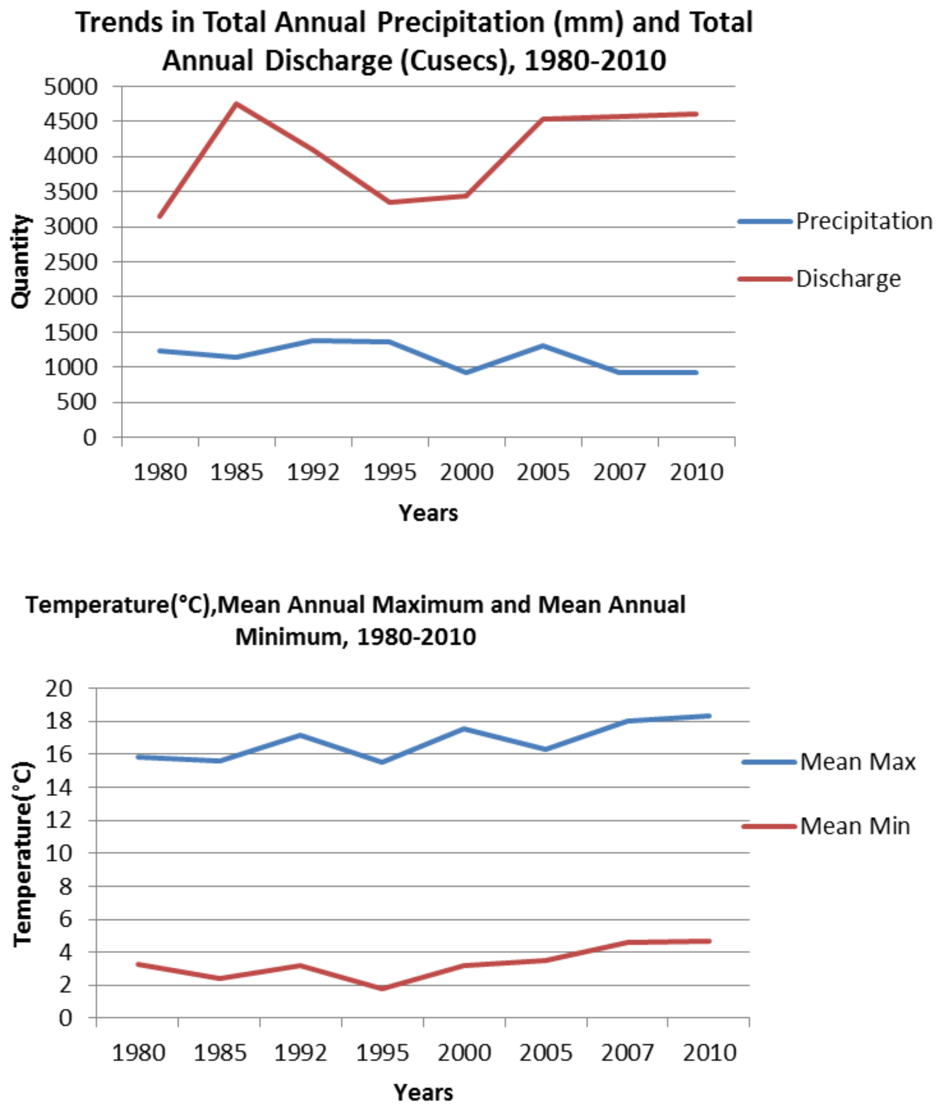


Figure 6. Trends in temperature, precipitation and discharge between 1980 and 2010 in Liddar basin.

hydro power capacity of the state, etc. Therefore there is a need to make efforts to save this precious source of water for the present as well as for future generations.

CONFLICT OF INTERESTS

The authors did not declare any conflict of interest.

ACKNOWLEDGEMENT

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